The Development of Quantum Mechanics

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Introduction

Working essentially independently, in the mid-1920's Heisenberg and Schrödinger both created a full form of Quantum Mechanics. How these two extraordinary events occurred has been extensively studied; a favorite reference is Max Jammer, **The Conceptual Development of Quantum Mechanics** (McGraw-Hill 1966).

Here we briefly outline some of the key features of these developments. Some of the material is well-known, but other parts of what follows are not. The level is consistent with an upper-year liberal arts course in modern physics without mathematics that is given at the University of Toronto.

Heisenberg's Matrix Mechanics

Heisenberg's starting point was the Bohr model of the atom. This model had been extended by Sommerfeld, and by the Summer of 1925 many physicists had learned through trial and error how to navigate through some of the morass of atomic physics. This circumstance, however, is far short from having a good *theory* of atomic physics.

Heisenberg attempted to build such a theory, and immediately ran into difficulties. He was attempting to make an analogy between the orbit of an electron about a nucleus and the familiar problem of a simple pendulum. However, he ended up in a "morass of complicated mathematical equations, with no way out." (**Physics and Beyond**, pg. 60.)

Then Heisenberg remembered a principle of Einstein's: that the theory decides what can be observed. Heisenberg applied this idea to his attempts to build an atomic theory by throwing out any attempt to describe the orbits of the electrons directly. Instead he restricted the variables in the theory to the observables, which in this case are the wavelengths and the intensities of the lines in the atomic spectra. As he commented, "I thought it more fitting to restrict myself to these, treating them, as it were, as representatives of the electron orbits." (*op. cit.* pg. 63.) And from this principle he built his complete form of Quantum Mechanics.

In a later conversation, Einstein admitted that he had used a similar principle in developing the theories of relativity, but in this case thought that Heisenberg had gone much too far. (*ibid.*)

In any case, since the observables, the wavelengths of the line spectra, are discontinuous the theory that Heisenberg built is similarly discontinuous. This formulation of Quantum Mechanics is often called *Matrix Mechanics*; we shall see that this distinguishes it from Schrödinger's theory.

Heisenberg first published his Matrix Mechanics in 1926 in the journal *Zeitschrift der Physick*.

Schrödingers's Wave Mechanics

In 1905 Einstein proposed that light, in addition to its well known nature as a wave of electric and magnetic fields, can be thought of as a particle, which now we call the *photon*. In 1923 Louis de Broglie proposed that particle-like objects, such as electrons, could also be thought of as some sort of wave. At this time de Broglie was a graduate student, and his proposal was part of his PhD thesis. His supervising committee didn't know what to make of this outlandish proposal and asked Schrödinger, who pronounced that the idea was "rubbish!" The committee went to Einstein, who essentially said that they should give the kid his PhD, since "there might be something to it." So that is how de Broglie got his PhD, and in 1926 Davisson and Germer actually saw electrons demonstrating an interference pattern.

In 1926 Schrödinger published a series of papers giving a full form of Quantum Mechanics; in this formulation the central idea is de Broglie's hypothesis. This formulation, then, is called *Wave Mechanics*. When earlier we stated that we could "explain" the ad hoc Bohr model by realising that the 'allowed orbits' of that model correspond to standing waves of electrons, we were describing how Wave Mechanics describes the theory of an atom.

It is interesting to note that the first of these papers appeared simultaneously to Heisenberg's first publication. Schrödinger's paper was in the journal *Annelen der Physick*, a competitor to the *Zeitschrift* journal that had published Heisenberg's work.

It is obvious that Schrödinger changed his mind about a wave aspect to electrons between 1923 and 1926. There is some controversy about how Schrödinger actually arrived at Wave Mechanics, but in the Fall of 1925, presumably as he was building his theory, he wrote an essay, **Seek for the Road**, which may provide some clues. (Reference: **My View of the World**, (Cambridge, 1964).

You may recall the Schrödinger's Cat paradox, which was first published in its "scientific form" in 1935 in *Zeitschrift der Physick*. However in his 1925 essay he recounts an ancient Sankhya Hindu paradox that, jazzed up with some technology, became the cat paradox. In that original form the paradox was cast in the form of two people, one looking at a garden, the other in a dark room. The modern equivalent would be one person looking in the box to see if the cat is alive or dead, while a second person waits out in the hall. As we discussed, in this modern form the state "collapses" for the first person while it does not collapse for the second person.

In 1925 Schrõdinger resolved that paradox the way the Vedantists did: he asserted that all consciousness is one. As he wrote:

"But it is quite easy to express the solution in words, thus: the plurality [of viewpoints] that we perceive is only *"an appearance*; *it is not real*. Vedantic philosophy, in which this is a fundamental dogma, has sought to clarify it by a number of analogies, one of the most attractive being the many-faceted crystal which, while showing hundreds of little pictures of what is in reality a single existent object, does not really multiply the object."

Here is another fragment of that essay:

"... you may suddenly come to see, in a flash, the profound rightness of the basic conviction of Vedanta: ... knowledge, feeling and choice are essentially eternal and unchangeable and numerically *one* in all men, nay in all sensitive beings."

Do you think that Schrödinger had such a flash of insight? Is this the sort of insight which in the Eastern traditions is sometimes called *enlightenment*?

Finally, Schrödinger himself makes an interesting analogy between Vedantic philosophy and modern physics:

"If finally we look back at that idea of Mach [that `the universe is not twice given'], we shall realize that it comes as near to the orthodox dogma of the Upanishads as it could possibly do without stating it *expressis verbis*. The external world and consciousness are one and the same thing."

Comparing the Two Forms of Quantum Mechanics

Despite their radically different worldview, shortly after their publication it was shown that Matrix Mechanics and Wave Mechanics are mathematically identical. In fact, Schrödinger was one of the people who did the proof.

Despite their formal equivalence, there seems to be more than just logic involved in the interpretation of the mathematics. For example, Heisenberg wrote:

"The more I ponder the physical part of Schrðdinger's theory, the more disgusting it appears to me."

while Schrödinger wrote:

"If one has to stick to this damned quantum jumping, then I regret ever having been involved in this thing."

In the 5th century of the current era, there was a bitter argument in India between the Sankhya Hindus and the Buddhists about the nature of Universal Flux. Debates were held which lasted for days, and would attract huge crowds. According to the Buddhists:

The phenomena consist of an infinity of discrete moments following one another almost without intervals.... There is no matter at all, flashes of energy follow one another and produce the illusion of stabilized phenomena. The universe is a *staccato* movement.

while according to the Hindus:

The phenomena are nothing but waves or fluctuations standing out upon the background of an eternal, all-pervading undifferentiated Matter with which they are identical. The universe represents a *legato* movement.

Reference: F. Theodor Stcherbatsky, **Buddhist Logic**, Vol I, pg 83.

Even allowing for the possibility that Schrödinger's Wave Mechanics may have been influenced by Hindu philosophy, the parallels between the Buddhist-Hindu argument and the Heisenberg-Schrödinger aesthetic clash are striking.

Discussion

Earlier we saw that two formally identical theories of antimatter, due to Dirac and Feynman, are interpreted in radically different ways. Now we see two formally identical formulations of Quantum Mechanics, which not only have radically different interpretations, but those interpretations apparently have a huge emotional and aesthetic content. In this section I shall briefly discuss some ideas about how this can be so.

In the humanities, the field of *Literary Criticism* is involved in part with trying to interpret what some author actually means when they wrote some particular passage. For an

outsider like me, it is absolutely amazing how just a few words in a poem can be interpreted so differently by different scholars.

This circumstance is one of the reasons why some have claimed that there really isn't any meaning in those few words, or much of anything else. This leads to the post-modern excesses of deconstruction, in my view.

I prefer to view these different interpretations as just a consequence of the fact that all *natural languages* are inherently ambiguous.

For example, consider the simple statement: *The plant is complete.* What is it that is complete? It could be a vegetable. It could be the act of fixing something in place. Or it could be a factory. In the usual case the meaning of a simple phrase like this is given by its context.

But in more sophisticated situations, there may be a range of meanings for a phrase and for a good writer all of those meanings are simultaneously being deployed.

Similarly, in mathematics one often puts a dot over a character: $\mathring{A}$. The meaning of the dot is ambiguous. It could mean we are referring to a unit of length called the Angstrom. It could mean that we are referring to the derivative of the variable A with respect to time. It could mean other things as well.

Thus, it is fair to argue that mathematics, the language of Physics, is a natural language with all of the levels of multiple meaning and ambiguity of other such languages. In this view, then, the strong positions of Heisenberg and Schrödinger on the worldview of Quantum Mechanics is similar to an argument between two scholars of literary criticism on the meaning of a T.S. Eliot poem.

About a half century ago, C.P. Snow wrote about how our culture seems to have bifurcated into two cultures, a scientific one and a non-scientific one. One contributing factor to this possible bifurcation is that scientists when they communicate amongst themselves use mathematics as one of the primary languages of that communication. For the many people who are math-phobic, then, this communication is unintelligible.

Of course, one of the major points of this course is a demonstration that one may discuss and understand science at a deep level without mathematics.

In any case, the analogy between interpretations of poems and interpretations of scientific theories that I made above puts me into direct opposition to much of the following by D.H. Lawrence:

"[Literary] criticism can never be a science: it is, in the first place, much too personal, and in the second, it is concerned with values that science ignores. The touchstone is emotion, not reason." -- **Phoenix: The Posthumous Papers**

Author

This document was written in March 2000 by David M. Harrison, Department of Physics, University of Toronto, mailto:harrison@physics.utoronto.ca.. This is version 1.6, date (m/d/y) 04/30/04.